CLAIMS

1. A method of simulating, in a machine, a string using a wave equation that relates movement of the string in time to force acting on the string,

wherein the force acting on the string simulates a stream of a fluid medium flowing relative to the string.

2. A method according to claim 1, wherein:

the simulated string is supported between two supports and is aligned at rest in a first direction between the two supports;

a first of the two supports allows movement in a second direction orthogonal to the first direction and a second of the two supports does not allow movement; and

the string is caused from rest to vibrate in a plane, which includes the first and second directions, by turbulence in the fluid flow causing the stream of fluid medium to exert a pressure on the string in the second direction.

3. A method according to claim 2, wherein:

movement of the string out of alignment with the first direction causes the stream of fluid medium flowing in the first direction to exert a force on the string in the second direction.

4. A method according to claim 1, wherein:

the simulated string is supported between two supports aligned in a first direction,

a first of the two supports is rigid and a second of the two supports allows movement in a second direction orthogonal to the first direction; and

the string is caused to vibrate in a plane, which includes the first and second directions, by the stream of fluid medium flowing in a direction having a component in the second direction.

5. A method according to claim 1, wherein:

the simulated string is supported between two supports aligned in an x-direction;

a first of the two supports allows movement in a y-direction orthogonal to the x-direction and a second of the two supports does not allow movement;

the string comprises a plurality of discrete elements aligned at rest in the x-direction and spaced apart by a distance dx; and

the discrete elements are able to move in discrete steps of time dt in the y-direction only.

6. A method according to claim 5, in which the string comprises a plurality of j discrete elements from j=0 at one end movably supported by the first support to j=x-1 at the opposite end immovably supported by the second support; wherein

j is an integer; and

the stream of fluid medium flows in the x-direction and exerts a pressure on the string between elements j=0 and j=1.

7. A method according to claim 6, wherein the force $F_{PRES}[n, 0]$ at time n acting on the immovably supported element j=0 due to the pressure on the string between the movably supported element j=0 and adjacent element j=1 is given by:

$$F_{PRES}[n, 0] = P * (y[n, 0] - y[n, 1]) / dx$$

in which:

P denotes the pressure exerted by the stream of fluid medium on the string between the movably supported element j=0 and adjacent element j=0;

y[n, 0] denotes the excursion of the movably supported element j=0 at time n; and

y[n, 1] denotes the excursion of the adjacent element j=1 at time n.

8. A method according to claim 6, wherein the force $F_{TURB}[n, 0]$ at time n acting on the immovably supported element j=0 due to the turbulence in the stream of fluid medium is given by:

$$F_{TURB}[n, 0] = C_{TURB} * N_{RND}[n]$$

in which:

C_{TURB} denotes a turbulence coefficient; and

$N_{RND}[n]$ denotes a random signal.

9. A method according to claim 8, wherein the random signal comprises a low pass filtered noise.

10. A method according to claim 6, wherein the excursion y[n+1, 0] of the movably supported element for the next sample due to the pressure on the string between the movably supported element j=0 and adjacent element j=1 is given by:

$$y[n+1, 0] = y[n, 0] + (F_{PRES}[n, 0] + F_{TURB}[n, 0]) * dt^2 / M[0]$$

in which:

y[n, 0] denotes the excursion of the movably supported element j=0 at time n; and

$F_{PRES}[n, 0]$ denotes the force at time n acting on the movably supported element j=0 due to the pressure on the string between the movably supported element j=0 and adjacent element j=1;

$F_{TURB}[n, 0]$ denotes the force at time n acting on the movably supported element j=0 due to the turbulence in the stream of fluid medium; and

M[0] denotes the mass of the movably supported element j=0.

11. A method according to claim 10, wherein the excursion y[n+1, 0] is limited.

12. A method according to claim 6, wherein the stream of the fluid medium exerts a pressure on the string between each of the elements; and

wherein the force F[n, j] at time n acting on each discrete element from j=1 to j=x-2 due to the pressure P is given by:

$$F[n, j] = P[j] * (y[n, j] - y[n, j-1]) / dx + P[j] * (y[n, j] - y[n, j+1]) / dx.$$

13. A method according to claim 12, wherein the pressure P decreases linearly or exponentially with increasing j

14. A method according to claim 5, wherein the wave equation is an approximation of the continuous wave equation

$$M\frac{\partial^2 y}{\partial t^2} = T\frac{\partial^2 y}{\partial x^2} - S\frac{\partial^4 y}{\partial x^4} + L_T\frac{\partial^3 y}{\partial x^2 \partial t} - L_S\frac{\partial^5 y}{\partial x^4 \partial t} - L_V\frac{\partial y}{\partial t} + F(x,t)$$

in which:

F(x, t) denotes an external force at coordinate x on the string at time t;

M denotes mass per length;

S denotes stiffness of the string;

T denotes tension of the string;

Ls denotes a loss associated with the stiffness of the string;

Lt denotes a loss associated with the tension of the string; and

Lv denotes a loss associated with the turbulent flow of the fluid medium.

15. A method according to claim 14, wherein the approximation of the continuous wave equation is the discrete recursion formula:

y[n+1, j] = (y[n, j-2] c1 + y[n, j-1] c2 + y[n, j] c3 + y[n, j+1] c2 + y[n, j+2] c1 + y[n-1, j-2] c4 + y[n-1, j-1] c5 + y[n-1, j] c6 + y[n1, j+1] c5 + y[n-1, j+2] c4) / M[j] + 2y[n, j] + F[n, j]/M[j]

in which:

dx = 1;

dt = 1;

y[n, j] denotes the excursion of discrete element j in the y-direction at time n;

y[n+1, j] denotes the excursion of discrete element j in the y-direction at time n+1;

y[n, j+1] denotes the excursion of discrete element j+1 in the y-direction at time n;

M[j] denotes the mass of discrete element j;

F[n, j] denotes an additional external force acting on a discrete element j at time n; and

c1 to c6 are coefficients, which depend on the material parameters of the string and the surrounding media.

16. A method according to claim 15, wherein

c1 = -(S + Ls);

c2 = T + 4S + Lt +4Ls;

c3 = -(2T +6S + Lv + 2Lt + 6Ls);

c4 = Ls;

c5 = -(Lt + 4Ls); and

c6 = Lv +2Lt +6Ls

17. A method according to claim 15, wherein the discrete recursion formula is solved for the elements adjacent the respective supports by providing a dummy element at opposite ends of the string so that the excursion y[n+1, -1] of a dummy element adjacent the movably supported element for the next sample is given by:

y[n+1, -1] = y[n+1, 0] - (y[n+1, 1] - y[n+1, 0])

and the excursion y[n+1, x] of a dummy element adjacent the immovably supported element for the next sample is given by:

y[n+1, x] = -y[n+1, x-2]

18. A method according to claim 1, further comprising generating a sound based on movement of the simulated string.

19. A machine readable medium providing executable computer program instructions which when executed cause a data processing system to perform a method of simulating, in a machine, a string using a wave equation that relates movement of the string in time to force acting on the string,

wherein the force acting on the string simulates a stream of a fluid medium flowing relative to the string.

20. A method according to claim 19, wherein:

the simulated string is supported between two supports and is aligned at rest in a first direction between the two supports;

a first of the two supports allows movement in a second direction orthogonal to the first direction and a second of the two supports does not allow movement; and

the string is caused from rest to vibrate in a plane, which includes the first and second directions, by turbulence in the fluid flow causing the stream of fluid medium to exert a pressure on the string in the second direction.

21. A method according to claim 20, wherein:

movement of the string out of alignment with the first direction causes the stream of fluid medium flowing in the first direction to exert a force on the string in the second direction.

22. A method according to claim 19, wherein:

the simulated string is supported between two supports aligned in a first direction,

a first of the two supports is rigid and a second of the two supports allows movement in a second direction orthogonal to the first direction; and

the string is caused to vibrate in a plane, which includes the first and second directions, by the stream of fluid medium flowing in a direction having a component in the second direction.

23. A method according to claim 19, wherein:

the simulated string is supported between two supports aligned in an x-direction;

a first of the two supports allows movement in a y-direction orthogonal to the x-direction and a second of the two supports does not allow movement;

the string comprises a plurality of discrete elements aligned at rest in the x-direction and spaced apart by a distance dx; and

the discrete elements are able to move in discrete steps of time dt in the y-direction only.

24. A method according to claim 23, in which the string comprises a plurality of j discrete elements from j=0 at one end movably supported by the first support to j=x-1 at the opposite end immovably supported by the second support; wherein

j is an integer; and

the stream of fluid medium flows in the x-direction and exerts a pressure on the string between elements j=0 and j=1.

25. A method according to claim 24, wherein the force $F_{PRES}[n, 0]$ at time n acting on the immovably supported element j=0 due to the pressure on the string between the movably supported element j=0 and adjacent element j=1 is given by:

$F_{PRES}[n, 0] = P * (y[n, 0] - y[n, 1]) / dx$

in which:

P denotes the pressure exerted by the stream of fluid medium on the string between the movably supported element j=0 and adjacent element j=0;

y[n, 0] denotes the excursion of the movably supported element j=0 at time n; and

y[n, 1] denotes the excursion of the adjacent element j=1 at time n.

26. A method according to claim 24, wherein the force $F_{TURB}[n, 0]$ at time n acting on the immovably supported element j=0 due to the turbulence in the stream of fluid medium is given by:

$F_{TURB}[n, 0] = C_{TURB} * N_{RND}[n]$

in which:

C_{TURB} denotes a turbulence coefficient; and

$N_{RND}[n]$ denotes a random signal.

27. A method according to claim 24, wherein the excursion y[n+1, 0] of the movably supported element for the next sample due to the pressure on the string between the movably supported element j=0 and adjacent element j=1 is given by:

$y[n+1, 0] = y[n, 0] + (F_{PRES}[n, 0] + F_{TURB}[n, 0]) * dt^2 / M[0]$

in which:

y[n, 0] denotes the excursion of the movably supported element j=0 at time n; and

$F_{PRES}[n, 0]$ denotes the force at time n acting on the movably supported element j=0 due to the pressure on the string between the movably supported element j=0 and adjacent element j=1;

$F_{TURB}[n, 0]$ denotes the force at time n acting on the movably supported element j=0 due to the turbulence in the stream of fluid medium; and

M[0] denotes the mass of the movably supported element j=0.

28. A method according to claim 27, wherein the excursion y[n+1, 0] is limited.

29. A method according to claim 24, wherein the stream of the fluid medium exerts a pressure on the string between each of the elements; and

wherein the force F[n, j] at time n acting on each discrete element from j=1 to j=x-2 due to the pressure P is given by:

F[n, j] = P[j] * (y[n, j] – y[n, j-1]) / dx + P[j] * (y[n, j] – y[n, j+1]) / dx.

30. A method according to claim 29, wherein the pressure P decreases linearly or exponentially with increasing j

31. A method according to claim 23, wherein the wave equation is an approximation of the continuous wave equation

$$M\frac{\partial^2 y}{\partial t^2} = T\frac{\partial^2 y}{\partial x^2} - S\frac{\partial^4 y}{\partial x^4} + L_T\frac{\partial^3 y}{\partial x^2 \partial t} - L_S\frac{\partial^5 y}{\partial x^4 \partial t} - L_V\frac{\partial y}{\partial t} + F(x,t)$$

in which:

F(x, t) denotes an external force at coordinate x on the string at time t;

M denotes mass per length;

S denotes stiffness of the string;

T denotes tension of the string;

Ls denotes a loss associated with the stiffness of the string;

Lt denotes a loss associated with the tension of the string; and

Lv denotes a loss associated with the turbulent flow of the fluid medium.

32. A method according to claim 31, wherein the approximation of the continuous wave equation is the discrete recursion formula:

y[n+1, j] = (y[n, j-2] c1 + y[n, j-1] c2 + y[n, j] c3 + y[n, j+1] c2 + y[n, j+2] c1 + y[n-1, j-2] c4 + y[n-1, j-1] c5 + y[n-1, j] c6 + y[n1, j+1] c5 + y[n-1, j+2] c4) / M[j] + 2y[n, j] + F[n, j]/M[j]

in which:

dx = 1;

$dt = 1$;

$y[n, j]$ denotes the excursion of discrete element j in the y-direction at time n;

$y[n+1, j]$ denotes the excursion of discrete element j in the y-direction at time n+1;

$y[n, j+1]$ denotes the excursion of discrete element j+1 in the y-direction at time n;

$M[j]$ denotes the mass of discrete element j;

$F[n, j]$ denotes an additional external force acting on a discrete element j at time n; and

c1 to c6 are coefficients, which depend on the material parameters of the string and the surrounding media.

33. A method according to claim 32, wherein

$c1 = -(S + Ls)$;

$c2 = T + 4S + Lt + 4Ls$;

$c3 = -(2T + 6S + Lv + 2Lt + 6Ls)$;

$c4 = Ls$;

$c5 = -(Lt + 4Ls)$; and

$c6 = Lv + 2Lt + 6Ls$

34. A method according to claim 32, wherein the discrete recursion formula is solved for the elements adjacent the respective supports by providing a dummy element at opposite ends of the string so that the excursion $y[n+1, -1]$ of a dummy element adjacent the movably supported element for the next sample is given by:

$$y[n+1, -1] = y[n+1, 0] - (y[n+1, 1] - y[n+1, 0])$$

and the excursion $y[n+1, x]$ of a dummy element adjacent the immovably supported element for the next sample is given by:

$$y[n+1, x] = -y[n+1, x-2]$$

35. A method according to claim 19, the method further comprising generating a sound based on movement of the simulated string.

36. An apparatus for simulating, in a machine, a string using a wave equation that relates movement of the string in time to force acting on the string,

wherein the force acting on the string simulates a stream of a fluid medium flowing relative to the string, said apparatus comprising:

means for storing data for said simulating; and

means for simulating.

37. An apparatus according to claim 36, wherein:

the simulated string is supported between two supports and is aligned at rest in a first direction between the two supports;

a first of the two supports allows movement in a second direction orthogonal to the first direction and a second of the two supports does not allow movement; and

the string is caused from rest to vibrate in a plane, which includes the first and second directions, by turbulence in the fluid flow causing the stream of fluid medium to exert a pressure on the string in the second direction.

38. An apparatus according to claim 37, wherein:

movement of the string out of alignment with the first direction causes the stream of fluid medium flowing in the first direction to exert a force on the string in the second direction.

39. An apparatus according to claim 36, wherein:

the simulated string is supported between two supports aligned in a first direction,

a first of the two supports is rigid and a second of the two supports allows movement in a second direction orthogonal to the first direction; and

the string is caused to vibrate in a plane, which includes the first and second directions, by the stream of fluid medium flowing in a direction having a component in the second direction.

40. An apparatus according to claim 36, wherein:

the simulated string is supported between two supports aligned in an x-direction;

a first of the two supports allows movement in a y-direction orthogonal to the x-direction and a second of the two supports does not allow movement;

the string comprises a plurality of discrete elements aligned at rest in the x-direction and spaced apart by a distance dx; and

the discrete elements are able to move in discrete steps of time dt in the y-direction only.

41. An apparatus according to claim 40, in which the string comprises a plurality of j discrete elements from j=0 at one end movably supported by the first support to j=x-1 at the opposite end immovably supported by the second support; wherein

j is an integer; and

the stream of fluid medium flows in the x-direction and exerts a pressure on the string between elements j=0 and j=1.

42. An apparatus according to claim 41, wherein the force $F_{PRES}[n, 0]$ at time n acting on the immovably supported element j=0 due to the pressure on the string between the movably supported element j=0 and adjacent element j=1 is given by:

$$F_{PRES}[n, 0] = P * (y[n, 0] - y[n, 1]) / dx$$

in which:

P denotes the pressure exerted by the stream of fluid medium on the string between the movably supported element j=0 and adjacent element j=0;

y[n, 0] denotes the excursion of the movably supported element j=0 at time n; and

y[n, 1] denotes the excursion of the adjacent element j=1 at time n.

43. An apparatus according to claim 41, wherein the force $F_{TURB}[n, 0]$ at time n acting on the immovably supported element j=0 due to the turbulence in the stream of fluid medium is given by:

$$F_{TURB}[n, 0] = C_{TURB} * N_{RND}[n]$$

in which:

C_{TURB} denotes a turbulence coefficient; and

$N_{RND}[n]$ denotes a random signal.

44. An apparatus according to claim 36, further comprising a means for generating sound based on said simulating.

45. An apparatus according to claim 41, wherein the excursion y[n+1, 0] of the movably supported element for the next sample due to the pressure on the string between the movably supported element j=0 and adjacent element j=1 is given by:

$$y[n+1, 0] = y[n, 0] + (F_{PRES}[n, 0] + F_{TURB}[n, 0]) * dt^2 / M[0]$$

in which:

y[n, 0] denotes the excursion of the movably supported element j=0 at time n; and

$F_{PRES}[n, 0]$ denotes the force at time n acting on the movably supported element j=0 due to the pressure on the string between the movably supported element j=0 and adjacent element j=1;

$F_{TURB}[n, 0]$ denotes the force at time n acting on the movably supported element j=0 due to the turbulence in the stream of fluid medium; and

M[0] denotes the mass of the movably supported element j=0.